Groundwater Management in the State of Punjab

M.P. Kaushal[1] and A.K. Jain[2]

[1]Professor and Head, [2]Professor, Dept. of Soil and Water Engineering
Punjab Agricultural University, Ludhiana

Abstract: Groundwater management strategy was considered as shifting the cropping pattern in such a way so as to reduce the area under the crop having high water requirements thus helping to reduce the demand for irrigation water. The crops of *Sirhind Canal Tract* in *kharif* season are paddy, cotton, maize and groundnut. Since paddy is a crop having higher water requirement, different percentage of the area under paddy was shifted to cotton, maize and groundnut in the ratio 3:1:1. The reduction in draft values were computed corresponding to 5, 10, 20 and 30% reduction in paddy area. The draft values were subtracted from the normal draft values for each node to get the reduced draft for different reductions in paddy area as an input to the model.

The results reveal that area under depth range of 10-15 m diminished from 48.38 per cent to 47.42, 46.43, 44.11 and 41.62 per cent when paddy was shifted by 5, 10, 20 and 30% respectively, whereas the area under depth range of 5-10 m increased. Thus the shifting of paddy crop with cotton, maize and groundnut would help to arrest declining water table situation in the state of Punjab. The policy issues for management of groundwater in the state have also been discussed.

INTRODUCTION

Adoption of high technology agriculture in the state of Punjab has increased the crop water demand manifold. Canal water supply being scarce, groundwater has emerged as an important resource to supplement the irrigation needs. However the indiscriminate withdrawal of groundwater has resulted in declining of water table in the state of Punjab. A detailed study of groundwater behaviour in two different tracts of Punjab viz. *Bist Doab tract* and *Sirhind Canal tract* was carried out. In these tracts the water table has been declining for the last two decades due to over exploitation. The groundwater behaviour has been simulated by adopting the finite difference based groundwater flow model.

BIST DOAB TRACT

Bist Doab tract, located in the North-East part of Punjab state–comprising the districts of Hoshiarpur, Jalandhar, Kapurthala and Nurpur Bedi block of Ropar district–covers an area of 8,49,720 hectares

(Fig. 1). On two sides it is bounded by Beas and Sutlej rivers and the third side is bounded by the Shivalik hills. The topography of most of the area in the tract is plain except some portion of Hoshiarpur district and Nurpur Bedi block. The normal annual rainfall is 715 mm. The sub surface aquifers are alluvial in nature. Irrigation is done by tubewells and network of canals. Tubewells are the major source of irrigation and accounts for approximately 90 per cent of the gross irrigated area.

Fig. 1. Bist Doab tract of Punjab state.

Groundwater Simulation

To simulate the seasonal groundwater behaviour, the finite difference based groundwater flow model 'MODFLOW' developed by Donald and Harbaugh (1988) was used. In this study it solves the two dimensional groundwater flow equation:

$$\frac{\partial \{K_{xx}\, \partial h/\partial x\}}{\partial x} + \frac{\partial \{K_{yy}\, \partial h/\partial y\}}{\partial y} - w = S_s\, \partial h/\partial t$$

where K_{xx} and K_{yy} are the hydraulic conductivity along x and y coordinate axes; h is the hydraulic head; w is the volumetric flux per unit volume representing source/sink; S_s is the specific storage of porous media and t is the time.

The ground water basin of *bist doab* tract was discretized into a finite difference grid (16 rows and 18 columns) with grid spacing of 8500 m × 8500 m. The block centered approach was used to simulate the groundwater flow within the aquifer. At the centre of each block, the value of hydraulic conductivity, specific yield, initial hydraulic heads (based on the observed water table records), elevation of bottom of aquifer, recharge rate and draft value were assigned as input to the model. The recharge to groundwater basin was computed due to percolation of rainfall, seepage from canal network, and because of return flow from irrigated areas. The recharge of each component was distributed as per the area of the cell falling in a particular block. The quantity of groundwater draft in each season was computed based upon the number of tubewells and unit draft values. The total draft values thus obtained were modified using multiplication factor based on variation in quantity of rainfall from normal rainfall values. Based upon the observed water level records (June/October) at different observation wells in the study area the water table contour maps were prepared and the values of the hydraulic heads at the centre of each of the grid cells were interpolated for the years from 1980-81 to 1992-93 for the month of June and October each year.

Based upon the water requirements of major crops being grown, average canal water supply, average discharge of a tubewell and average irrigated area, the simulation time for *kharif* and *rabi* season was taken as 40 days and 15 days, respectively for model runs.

Model Calibration

The groundwater model was calibrated using the season-wise historical data for the years 1980-81 to 1985-86. The model was first run for the year 1980-81 (kharif and rabi season) using the values of hydrologic parameters as obtained from well logs and observed hydraulic heads for June, 1980 as the initial condition. The hydraulic heads computed for October, 1980 were compared with the observed values of October, 1980. Similarly another run was made with initial conditions as the observed hydraulic heads of October, 1980 to get the hydraulic heads for June, 1981. The hydraulic heads computed for June, 1981 were compared with the observed values of June, 1981. A significant difference was observed between the observed and computed values of hydraulic heads. Therefore, a sensitivity analysis of hydraulic parameters was carried out before the model is used for validation. The sensitivity of the model to variations in specific yield and hydraulic conductivity was studied. The values of these aquifer parameters were adjusted within allowable limits, to achieve simulation error (difference between the computed and historical hydraulic heads) within acceptable limits. The average absolute simulation error (Table 1) during calibration period was 1.07 metres in *kharif* and 0.986 metres in *rabi* season, which may be considered as acceptable error.

Table 1. Simulation error between Observed and Simulated hydraulic heads

Year	*Rabi*	*Kharif*
Calibration period		
1980-81	—	0.82
1981-82	0.92	1.05
1982-83	0.65	0.70
1983-84	0.95	0.99
1984-85	1.19	1.25
1985-86	1.22	1.61
Average	0.986	1.07
Validation period		
1986-87	1.18	1.20
1987-88	1.24	0.86
1988-89	1.64	1.08
1989-90	1.66	1.28
1990-91	1.31	0.79
1991-92	1.56	1.12
1992-93	0.83	1.13
Average	1.12	1.065

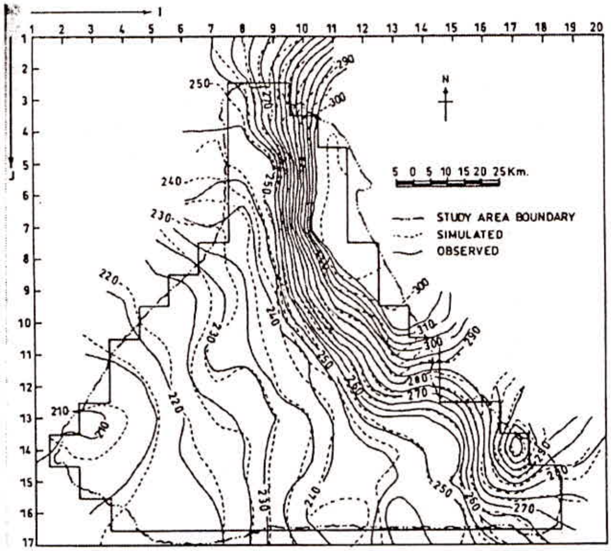

Fig. 2. Computed and observed hydraulic heads (October, 1991).

Model Validation

The model was validated for the years from 1986-87 to 1992-93 by using the modified parameters. The average simulation error for validation period (Table 1) was 1.065 metres in *kharif* and 1.12 metres in *rabi*, which may be considered as acceptable error (Klempt et al., 1979; Boonstra and De Ridder, 1981; Sondhi, 1989 and Jain, 1995). The typical observed and corresponding simulated water table contour maps are given in Fig. 2. A good agreement was obtained between predicted and observed water levels.

SIRHIND CANAL TRACT

The Sirhind canal tract lies south of Sutluj river. Towards east and north-east, it is surrounded by Shivalik foothill zone and towards south and south-east, the tract is surrounded by river Gaggar, towards south west by Bakhra Main Line canal (BML) while towards the west Rajasthan canal flow. The total area of the tract is 26,92,030 ha, comprising the entire districts of Bhathinda, Ludhiana, Patiala, Ropar and Sangrur and parts of the Faridkot and Ferozpur districts. The slope of the land is from north-east to south-west. The soil is formed through alluvial deposits and vary from loamy sand to sandy loam. The normal annual rainfall varies from 1000 mm in Ropar districts to less than 400 mm in south-western districts. The Sirhind canal tract has a wide canal network. The irrigation is also being carried out using ground water through tubewells. The subsurface aquifers in this tract are alluvial in nature and composed of sandy clay, gravels, pebbles and kankars.

The groundwater potential was estimated by computing various components of the groundwater recharge and water balance equation (Anonymous, 1984). The average groundwater potential has been estimated as 61,187 ha-m. The recharge from rainfall, canal network and return flow from the irrigated area was computed as 23.83, 12.11 and 64.06 per cent respectively.

Groundwater Simulation

The digital computer model 'PLASM' developed by the Prickett and Lonnquist with modifications to allow simulation of an unconfined aquifer as prevailing in the Sirhind canal tract was used. The aquifer was discretized into a finite difference grid (24 columns and 18 rows) with grid spacing of the 10,000 m × 10,000 m. The water level contour map based upon the observed water level records at observation wells in the area were interpolated to get hydraulic potential at all nodal points. The annual pumping period was 1200 hrs (50 days). Accordingly number of the time increments (NSTEPS) was 14 and an initial time increment (DELTA) was 0.84. Each node was assigned the value of transmissibility, specific yield, initial head, net withdrawal rate, hydraulic conductivity and elevation of bottom of aquifer. The study area is surrounded by rivers Sutluj and Gaggar on two sides. On other two sides, the area is surrounded by BML and Rajasthan feeder canal. The small portion of the area towards the North-east is surrounded by Shivalik foothills. The river and canal boundaries were considered constant head boundaries and a high value of storage factors (10^{20} sq. m.) was assigned along these boundaries. Along the Shivalik foothill boundary, a very low value of transmissibility was assigned considering that no flow of water occurs across the boundary.

Thus the model runs with net annual recharge at each node (I, J) set to zero. The result thus obtained needs to be corrected for taking into account recharge so as to compare the predicted and observed hydraulics potentials. The annual recharge was spacially distributed with the help of recharge distribution coefficient using technique proposed by Sondhi et al. (1989).

The groundwater simulation model was calibrated for years 1982-83 to 1986-87 and validated for years 1987-88 to 1990-91.

Groundwater Management

Groundwater management strategy was considered as shifting the cropping pattern in such a way so as to reduce the area under the crop having high water requirements thus helping to reduce the demand for irrigation water. The crops of Sirhind Canal Tract in kharif season are paddy, cotton, maize and groundnut. The area under these crops is given in Table 2 for the year 1994-95 (Anonymous, 1995). Since paddy is a crop having higher water requirement, different percentage of the area under paddy was shifted to cotton, maize and groundnut in the ratio 3:1:1. The reduction in draft values for 5, 10, 20 and 30% reduction of the paddy area were calculated. The draft values were subtracted from the normal draft values (1994-95) for each node to get the reduced draft for different reductions in paddy

Table 2. Area under major kharif crops in the study area for the year 1994-95

	Cropped area ('00 ha)			
District	*Paddy*	*Cotton*	*Maize*	*Groundnut*
Bhatinda	1100	2413	—	—
Faridkot	1750	2028	—	7
Ferozpur	1049	110	8	—
Ludhiana	2440	20	40	10
Patiala	3020	10	90	—
Ropar	540	—	300	—
Sangrur	3347	320	10	20

area. The simulation model was first run with normal draft value and predictions for the water level for the year 1995 were made.

The model was then run with reduced draft values and predicted water level values were compared with those for normal draft values. Water table depth map was prepared and area falling under different water table depths were calculated. The results indicated that after the shift in cropping pattern, area falling under deep water table condition diminishes.

The area under depth range of 10-15 m diminished from 48.38 per cent to 47.42, 46.43, 44.11 and 41.62 per cent when paddy was shifted by 5, 10, 20 and 30% respectively (Table 3), whereas the area under depth range of 5-10 m increased. Thus shifting of the cropping pattern resulted in arresting the water table condition in the Sirhind Canal Tract of Punjab (Marok, J.S. et al., 2000).

Table 3. Percentage area under different water table depths obtained after reduction in paddy area of Sirhind Canal Tract (1995)

	Reduction in Paddy Area				
Depth (m)	*Under normal conditions*	*5 per cent*	*10 per cent*	*20 per cent*	*30 per cent*
< 3	0.11 (2961)	0.12 (3230)	0.12 (3230)	0.12 (3230)	0.13 (3499)
3-5	3.88 (1,04,451)	3.97 (1,06,874)	4.07 (1,09,566)	4.27 (1,14,950)	4.47 (1,20,334)
5-10	46.98 (12,64,716)	48.11 (12,95,136)	49.17 (13,23,671)	51.46 (13,85,319)	53.78 (14,47,774)
10-15	48.38 (13,02,404)	47.42 (12,76,560)	46.43 (12,49,910)	44.11 (11,87,454)	41.62 (11,20,423)
> 15	0.65 (17,498)	0.38 (10,230)	0.21 (5653)	0.04 (1077)	0.00 (0)

(Figures in parentheses indicate area in hectares)

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REFERENCES

Anonymous (1984). Report of the Groundwater Estimation Committee—Groundwater Estimation Methodology. Ministry of Irrigation, Govt. of India, New Delhi

Anonymous (1995). Statistical Abstract of Punjab. Economic Advisor, Govt. of Punjab, Chandigarh.

Boonstra, J. and de Ridder, N.A. (1981). Numerical modelling of ground water basins. International Institute of Land Reclamation and Improvement, Wageningen, The Netherlands. Publication No. 29: 226.

Jain, A.K. (1995). Development of an expert system for optimal utilization of water resources. Ph.D. thesis, Punjab Agricultural University, Ludhiana. India.

Klempt, W.B., Knowlees, T.R., Elder, G.R. and Sieh, T.W. (1979). Ground water resources and model applications for the Edwards (Balcone's Fault Zone) aquifers in San Antonio Region. Report 239. Texas Dept. of Water Resources, Austin. Texas: 88.

Marok, J.S., Kaushal, M.P., Panesar, P.S. (2000). Groundware Management in Sirhind canal tract of Punjab. *J. of Res. Punjab Agric. Univ.* **37(1-2):** 105-113.

McDonald, M.G. and Harbough, A.W. (1988). A modular three dimensional finite difference ground water flow model. USGS Techonques of water resources Investigations. Book No. 6.

Prickett, T.A. and Lonnquist, C.G. (1971). *Selected Digital Computer Technique for Groundwater Resources Evaluation.* Bull. 55, p. 62 Illinois State Water Survey, Urbana.

Sondhi, S.K., Rao, N.H. and Sarma, P.B.S. (1989). Assessment of ground water potential for conjunctive water use in a large Irrigation Project in India. *Journal of Hydrology*, **107:** 283-298.